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**ROSAT ALL-SKY SURVEY
ON THE EINSTEIN EMSS SAMPLE**

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Grant NAG5-1428

Final Report

For the Period 1 October 1990 through 30 September 1992

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November 1992

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

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The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

N93-15340

Unclass

G3/89 0136501

(NASA-CR-191627) ROSAT ALL-SKY
SURVEY ON THE EINSTEIN EMSS SAMPLE
Final Report, 1 Oct. 1990 - 30 Sep.
1992 (Smithsonian Institution)
7 p

The NASA Technical Officer for this grant is Dr. Robert Petre, National Aeronautics and Space Administration, Code 666, Laboratory for High Energy Astrophysics, Space Sciences Directorate, Goddard Space Flight Center, Greenbelt, Maryland 20771.

ABSTRACT

The cosmological evolution and the luminosity function (XLF) of X-ray selected Active Galactic Nuclei (AGNs) are discussed. The sample used is extracted from the *Einstein* Observatory Extended Medium Sensitivity Survey (EMSS) and consists of more than 420 objects. Preliminary results from the ROSAT All-Sky Survey data confirm the correctness of the optical identification of the EMSS sources, thus giving confidence to the results obtained from the analysis of the AGNs sample. The XLF observed at different redshifts (up to $z \sim 2$) gives *direct* evidence of cosmological evolution. Data have been analyzed within the framework of luminosity evolution models and the two most common evolutionary forms, $L_x(z) = L_x(0) \times e^{C\tau}$ and $L_x(z) = L_x(0) \times (1+z)^C$, have been considered. Luminosity dependent evolution is required if the evolution function has the exponential form, whereas the simpler pure luminosity evolution model is still acceptable if the evolution function has the power law form. Using the whole sample of objects the number-counts and the de-evolved (@ $z=0$) XLF have been derived. A comparison of the EMSS data with preliminary ROSAT results presented at this meeting indicates an overall agreement.

INTRODUCTION

The study of the cosmological properties of AGNs can shed light on the physics of the AGNs phenomenon (Cavaliere, et al., 1971), on their contribution to the cosmic X-ray background (Maccacaro, et al., 1984), and eventually on the epoch of their formation, and on the connection between AGNs and normal galaxies (Cavaliere and Padovani., 1989).

In this paper we summarize and update the results from our ongoing effort aimed at the understanding of the statistical properties of X-ray selected AGNs. A thorough discussion of the EMSS AGNs sample, of the method of analysis and of the results so far obtained can be found in Maccacaro et al. (1991) and Della Ceca et al. (1992). The EMSS is described by Gioia et al. (1990) and Stocke et al. (1991).

A Hubble constant of $50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and a Friedmann universe with a deceleration parameter $q_0 = 0$ are assumed. We denote by L_x the observed (0.3-3.5) keV X-ray luminosity computed in the source comoving frame.

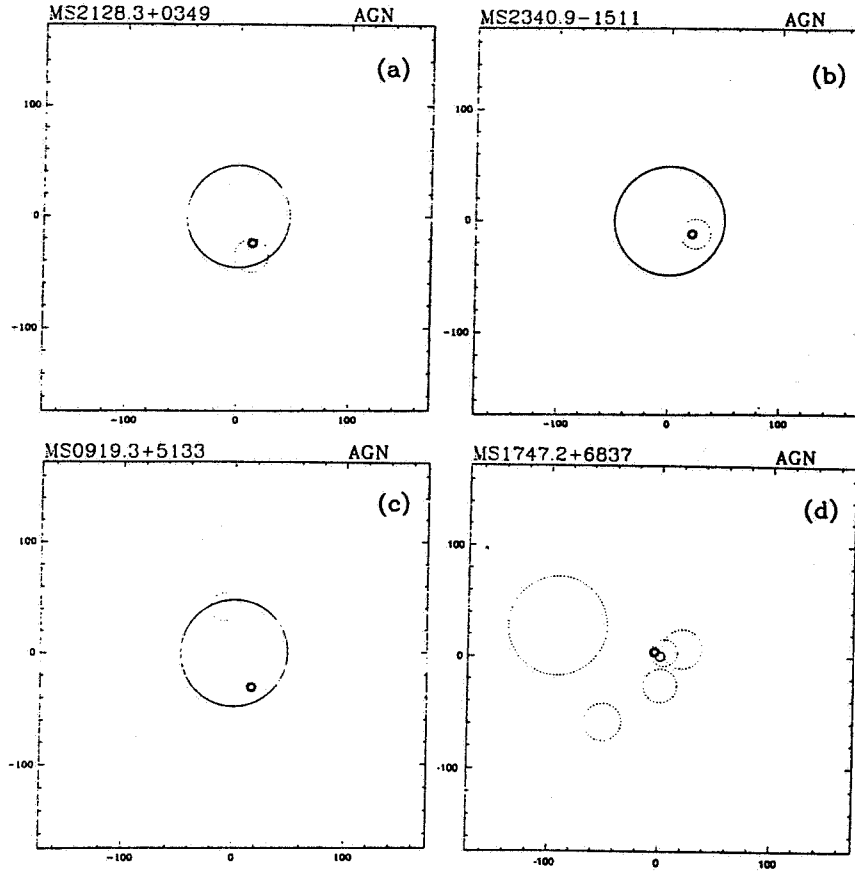


Fig 1. In all panels the continuous circle represents the Einstein error circle while the dashed circle represents the RASS error circle. The position of the ID is indicated. Scale is in arcseconds. For MS1747.2+6837 (1d) there are several RASS detections characterized by inconsistent positions, thus indicating the preliminary nature of the RASS analysis.

THE OBSERVED X-RAY LUMINOSITY FUNCTIONS

The large number of objects at our disposal and their coverage of the $L_x - z$ plane allow us to derive the AGN XLF at different redshifts directly from the data in a *model independent* way (Fig. 2).

The individual luminosity functions *do not overlap* but rather show a systematic shift toward higher luminosities as one moves from low to high redshifts, thus giving *direct* evidence for cosmological evolution.

However, we are not able yet to determine univocally the evolutionary law which best describes the AGNs behaviour. To do so a sampling of the luminosity function over a broader range of luminosities in each redshift shell is needed. We have thus limited our evolution analysis to the *assumption* of evolution models and the derivation of best fit parameters.

It is worth noting that the obtained XLFs are in excellent agreement with those obtained from preliminary ROSAT data (Boyle, private communication). The ROSAT sample used is fairly small and results from a deep observation of a very small area of sky. Therefore, at each redshift the ROSAT data sample much fainter regions of the XLF than

THE RELIABILITY OF THE EMSS OPTICAL IDENTIFICATIONS

As the analysis of the statistical properties of X-ray selected AGNs becomes more detailed, consistency, as well as significant differences, between the properties of soft x-ray selected AGNs and those of AGNs selected at other wavelengths emerge (Della Ceca et al., in preparation). It is thus important to assess the reliability of the optical identification of the EMSS sources (see Stocke et al. 1991) and, consequently, of the composition of the AGN sample so as to determine whether the differences are real and worth being investigated or whether they are due to a number of interlopers in the sample. We have therefore initiated a collaboration with colleagues here at MPE on the comparison of the Einstein and ROSAT All-Sky Survey (RASS) data on the EMSS sources. Preliminary results are becoming available and indicate that the very large majority of the EMSS identification are correct.

So far 367 EMSS sources have been detected in the RASS. For the remaining 468 we have either an upper limit or no information, since the RASS data have not been fully analyzed yet. The very large majority of the upper limits are due to lack of sensitivity since the RASS data are being analyzed at present in single strips and the overlapping strips have not been coadded yet. We expect that more EMSS sources will be eventually detected once this procedure will be implemented thus maximizing the RASS sensitivity.

For the purpose of assessing the reliability of the EMSS identification we have excluded from our analysis sources identified with clusters of galaxies (since in these cases the optical position of the source is not well determined as in the cases where the optical counterpart is a single object) and EMSS sources which are still unidentified. For 254 of the 309 identified, non-cluster EMSS sources detected in the RASS, we have a PSPC error circle which is significantly smaller than the Einstein IPC error circle and is consistent with the position of the optical identification (in 75% of the cases the PSPC error circle is more than 5 times smaller than the Einstein IPC error circle). Examples are given in Fig. 1a and 1b. For 21 sources the ROSAT error circle does not represent a significant positional improvement over the Einstein error circle (in most cases an Einstein HRI position was available and the identification is already certain). Finally we are left with a number of sources for which the RASS position is either marginally inconsistent with the position of the identification (26) or definitely inconsistent (8) (see Fig. 1c). We should point out however that these inconsistencies are not a firm indication of an incorrect identification. There are in fact a number of sources for which several RASS detections are available and in some cases not all ROSAT position are consistent with each other (an example is given in Fig. 1d). This is probably due to the preliminary nature of the RASS analysis.

We can thus conclude that we are able to confirm the correctness of the optical id of the EMSS sources in more than 90% of the cases. This percentage will increase when the reprocessing of the RASS data, with improved software and calibrations, will become available.

those sampled by the EMSS. The ROSAT data fall on the low luminosity extrapolation of the luminosity functions shown in Fig. 2.

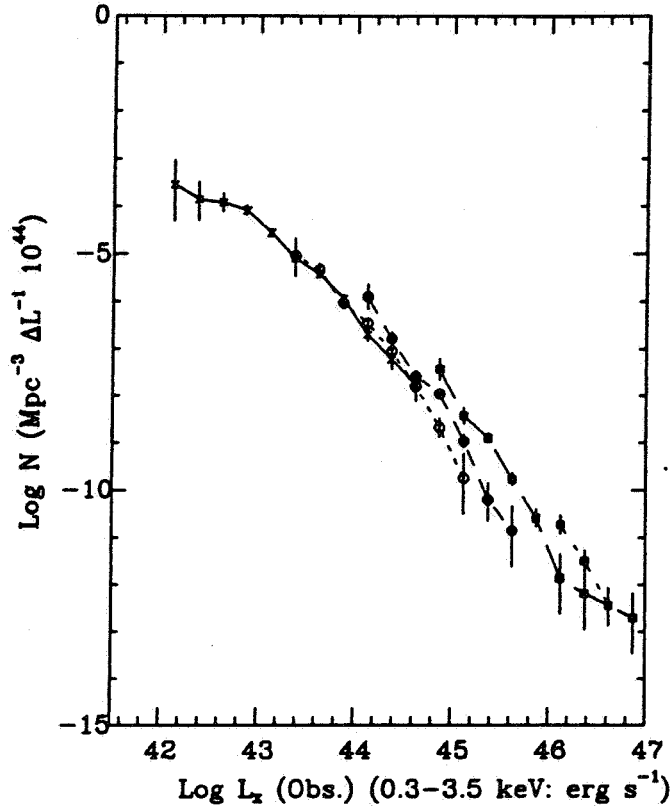


Fig. 2. The XLFs derived in various redshift shells defined so as to correspond to a uniform increase in look-back time τ of 0.15. In each shell, data have been binned in bins of equal logarithmic width of 0.25; 1σ error bars are determined by the number of objects in each bin (adapted from Maccacaro et al., 1991).

THE COSMOLOGICAL EVOLUTION OF AGNs IN THE X-RAY DOMAIN

To analyze the cosmological evolution of AGNs we have used the variable V_e/V_a (Avni and Bahcall 1980). We have first tested the hypothesis that X-ray selected AGNs are uniformly distributed in space and rejected it at more than 99.99% confidence level. Next we have used an evolutionary law such that V_e/V_a for our sources are uniformly distributed. The data have been analyzed within the framework of pure luminosity evolution models, and the two most common evolutionary forms, the *exponential form* $L_x(z) = L_x(0) e^{C\tau}$ and the *power law form* $L_x(z) = L_x(0) (1+z)^C$, have been considered. Here $L_x(0)$ is the present epoch luminosity, C is the evolution parameter and τ is the look-back time.

To study the cosmological evolution in deeper details than previously done, we have analyzed it as a function of luminosity in order to establish if there is any evidence of luminosity dependent evolution.

We have found that Luminosity Dependent Luminosity Evolution is necessary if the evolution function has the exponential form. To quantify this luminosity dependence we have assumed a linear relationship of the evolution parameter k_L on the X-ray luminosity, as given by, $L_x(z) = L_x(0) e^{k_L [Log(L_x(0)) - 42] \tau}$, to hold over the range of the sampled luminosities. We find that our data set is best described by $k_L = 2.2$ with an associated 68% and 95% confidence intervals of [1.98-2.42] and [1.75-2.64] respectively.

On the contrary, a Pure Luminosity Evolution is still acceptable in the case of the power law evolution form; the best fit value of C is 2.56 (the associated 68% and

95% confidence intervals are [2.39-2.73] and [2.19-2.88] respectively). Similar results were obtained, in the optical domain, by Marshall (1985) from the analysis of a sample of optically selected QSOs with $z < 2.2$ and $B < 20$.

Using the full sample of objects and within the framework of the power law PLE model (with $C=2.56$: best fit), we have then derived the de-evolved ($z=0$) XLF shown in Fig. 3.

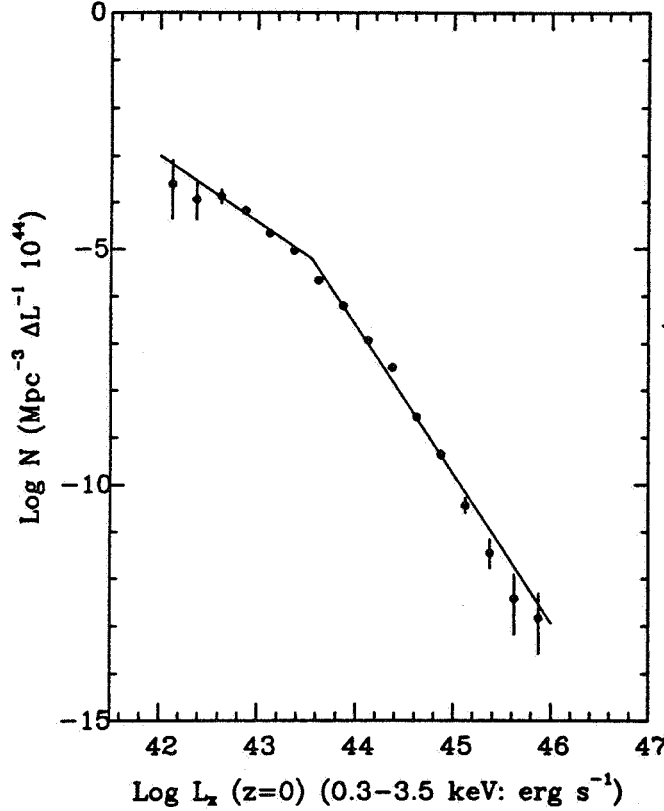


Fig. 3. The de-evolved ($z=0$) X-ray luminosity function. Data have been binned in bins of equal logarithmic width of 0.25; 1σ error bars are determined by the number of objects in each bin (adapted from Della Ceca and Maccacaro, 1991).

The two power laws, shown in Fig. 3, represent the best fit to the *unbinned data* using the maximum likelihood method. At low luminosities ($L_x(0) < 3.60 \times 10^{43} \text{ erg s}^{-1}$) the best fit slope is $\gamma_1 = 1.42$ ($K_1 = 1.45 \times 10^{-6} \text{ Mpc}^{-3} L_{44}^{\gamma_1-1}$), while at high luminosities the best fit slope is $\gamma_2 = 3.16$ ($K_2 = 2.45 \times 10^{-7} \text{ Mpc}^{-3} L_{44}^{\gamma_2-1}$).

Using the best-fit values for the evolution of AGNs and for their volume density, we have found that they contribute $\sim 40\%$ to the 2 Kev diffuse X-ray background.

THE NUMBER COUNTS RELATION

The virtually complete identification rate of the EMSS (Stocke et al. 1991) allowed us to derive the $\text{Log } N(>S) - \text{Log } S$ relation for the AGNs subsample (Fig. 4: solid lines). It is described by a power law $N(>S) = K S^{-\alpha}$ with best fit values for the slope $\alpha = 1.61 \pm 0.06$ and normalization $K = 4.92 \times 10^{-21} \text{ deg}^{-2}$.

We have compared the EMSS AGNs $\text{Log } N(>S) - \text{Log } S$ with the recently obtained extragalactic ROSAT $\text{Log } N(>S) - \text{Log } S$ (Shanks et al., 1991). The two $\text{Log } N(>S) - \text{Log } S$ show a good agreement in the region of overlap, especially if one considers that the conversion between the two bands is made under the simplifying hypothesis of a single power law spectrum of $\alpha = 1$. It is worth to note that the ROSAT extragalactic Log

$N(>S)$ – $\text{Log } S$ has a best fit slope of 1.6 ± 0.3 , to be compared with our determination of 1.61 ± 0.06 . This fact strongly suggests that the AGNs could be still the dominant source population up to fluxes of the order of $\sim 2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$.

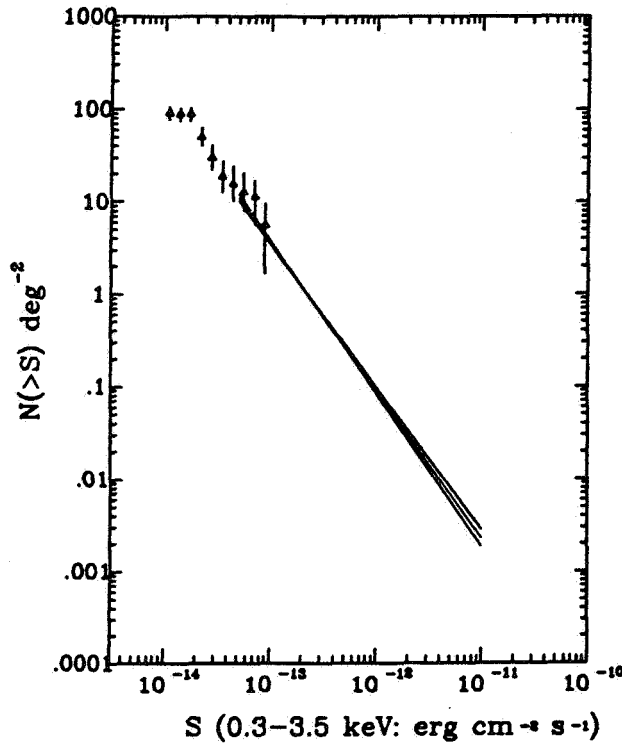


Fig. 4. The solid lines indicate the $\text{Log } N(>S)$ – $\text{Log } S$ relationship for the EMSS AGNs sample (best-fit and $\pm 1\sigma$ errors on the slope). The filled triangles represent the non-stellar ROSAT $\text{Log } N(>S)$ – $\text{Log } S$ relationship converted into the (0.3–3.5) keV energy band assuming that all sources are described by a power law spectrum with energy index of 1 (adapted from Della Ceca et al., 1992).

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